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Research on the Operational Characteristics of Diverging Area on Expressway Off-Ramp Based on Different Restricted Strategy of Lane

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Abstract

In order to find the operational characteristics of diverging area on expressway off-ramp with Vehicle Type Restricted Strategy(VTRS) and Vehicle Type Unrestricted Strategy(VTUS) in different lane, this paper analyzed the distribution of vehicle type in the each lane, in use of the data which is investigated from diverging area on the two expressway off-ramp with different operational strategy of lane. Furthermore, the χ^2 test technology was used to do the hypothesis test on the headway distribution. The result shows that the shift-negative-exponential distribution can well reflect the headway distribution of deceleration lane, and the first-order or the second-order Erlang distribution can well reflect the headway distribution of mainline. Finally, the conclusion can provide an important theoretical basis for the freeway off-ramp planning, designing, and management.

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1. Introduction

The capacity of diverging area on expressway off-ramp is less than expressway basic section's because of disturbance of deceleration and lane-changing behavior between going straight vehicles and right-turning vehicles. Thus, it is considered as the bottleneck and accident black-spots. With the increase of lane number and the change of operational strategy in multi-lane (more than four lanes in bidirectional) expressway, the characteristics of car-flow become more complexity and the operational safety and efficient is affected. As the increase of multi-lane expressway with Vehicle Type Restricted Strategy(VTRS) in different lane, the characteristic of diverging area on the off-ramp should be studied, so that it can provide the reference for the diverging area designing and management.

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The rest of paper is organized as follows. In the next section, the literature with traffic characteristics of expressway is reviewed. Then the process of data collection and selection is analyzed. In the subsequent section, the distribution characteristics of vehicle type on the expressway with different traffic rules is discussed. Finally, the distribution characteristics of headway on the expressway with different traffic rules is analyzed.

Nomenclature

- | | |
|---|--|
| A | VTRS of Vehicle Type Restricted Strategy and |
| B | VTUS of Vehicle Type Unrestricted Strategy |

2. Literature Review

The characteristic of diverge and the jam on the diverging area has been analyzed by many researchers at home and board. The four-lane expressway with vehicle type unrestricted strategy in different lane, is considered as the research objective in their paper. G.F. Newell(1999) researched the jam phenomenon on the expressway off-ramp preliminarily⁰. Cassidy(2000) find that vehicles in queue which overflow from downstream intersection of off-ramp to the diverging area, can affect the operational status on expressway mainline severely. Therefore, the relationship between the length of queue on off-ramp and the ratio of diverging vehicles was studied, and the principle of bottleneck formed was found⁰. Juan Carlos(2002) et al studied the operational mechanism of jam on the off-ramp⁰. R. Horowitz(2000) discussed some typical behavior with longitudinal and transverse control in the car-flow, such as merging, diverging, lane-changing and so on^[4]. Chen Yongmao(2010) analyzed the characteristic of merging and diverging on the expanding section of four-lane expressway, and put forward the model of dynamic merging based on signal control⁰. Li Tiezhu et al(2001) analyzed the traffic characteristics, such as speed, acceleration, deceleration, the distribution of merging points, and merging gap of ramp vehicles in the merging (diverging) zones of acceleration (deceleration) lanes of expressway on the basis of investigation⁰. Zhao Xiaocui et al(2012) studied the characteristic of diverging area on expressway off-ramp by use of detector NC200, and set up the headway distribution model in different flow⁰.

3. Data Collection and Selection

3.1. Process of Data Collection

In order to analysis the car-flow characteristics between the VTRS and VTUS on the diverging area of expressway off-ramp, two expressways are selected, one is Expressway H and the other is Expressway S. They both are located in Zhejiang Province, China. There are six lanes on its mainline and the exit we selected is of directional deceleration lane. But the operational strategy of lane in the mainline is different, Vehicle Type Restricted Strategy(VTRS) and Vehicle Type Unrestricted Strategy(VTUS)in different lane is applied in Expressway H and Expressway S respectively. For the purpose of expression simply, the serial number of lanes is set as follow in this paper: Lane1 is in the name of the far right lane expect deceleration lane on the expressway, Lane2 is in the name of the middle of lanes on the expressway, and the Lane3 is in the name of the far left lane on the expressway. In the VTRS, the heavy or large freight cars are allowed to run only in Lane1, the middle or small freight cars and the large or middle passenger cars are allowed to run in lane2, the small cars are allowed to run in lane3. In the VTUS, each kind of cars can run in each lane. In line with road traffic safety law, the slower car should run on the right lane of expressway, and the rapid cars should run on the left lane of expressway.

In this survey, the video camera is fixed on the gantry that is about 100 meters in front of the end of off-ramp diverging area, and the location of data collection is about 100 meters apart from the end of off-ramp diverging area. The data of volume and headway is recorded from the video. The information about location and time of data collection is in table 1.

Table 1 The location information of data collection

	Expressway H	Expressway S
Number of Lane	Six Lanes in bidirectional	Six Lanes in bidirectional
Type of diverging area	With Directional Deceleration Lane	With Directional Deceleration Lane
Operational Strategy	VTRS	VTUS
Site of Data Collection	Exit Site in Stake No. K43	Exit Site in Stake No. K61+700
Time of Data Collection	8:00-12:00 am, August 19, 2010	8:00-12:00 am, August 24, 2010

Time of Data Selection

10:50-11:24 am, August 19, 2010

8:59-9:31 am, August 19, 2010

3.2. Type of Data

The sample that used in this paper is selected with three steps. Firstly, the video was watched detailed and ensured that no accident and dangerous drive behavior occur in half an hour. Secondly, the data was recorded from the video in fixed time. Thirdly, the abnormal data was excluded and the sample is determined. Finally, the sample includes 2219 vehicle type and 2211 headway. The detail data is show in table2 and table3.

Table 2 The number of data on the two expressways with different operational strategy

Expressway	Deceleration Lane	Lane1	Lane2	Lane3
Number on the H	133	236	281	418
Number on the S	156	120	372	503

Table 3 The ratio of each vehicle type on the two expressways with different operational strategy

VTRS	Vehicle Type	Small Cars	Middle or Small Fright Cars	Large or Middle Passenger Cars	Heavy or Large Freight Cars
	Ratio in the deceleration lane (%)	38.6	27.9	14.3	19.3
	Ratio in Lane1 (%)	3.39	41.05	3.02	52.54
	Ratio in Lane2 (%)	39.86	23.13	19.22	17.79
	Ratio in Lane3 (%)	94.74	0.48	4.07	0.72
VTUS	Vehicle Type	Small Cars	Middle or Small Fright Cars	Large or Middle Passenger Cars	Heavy or Large Freight Cars
	Ratio in the deceleration lane (%)	40.5	21.7	27.0	10.8
	Ratio in Lane1 (%)	35.83	20.83	9.17	34.17
	Ratio in Lane2 (%)	44.89	16.13	6.45	32.53
	Ratio in Lan3 (%)	77.14	5.37	7.75	9.74

4. Distribution of Vehicle Type

4.1. Comparison and Analysis the Number of Vehicle Type

According to table 3, we can find that the ratio of each vehicle type in deceleration lanes is similar, though the operational strategy is different. When VTRS is used on the expressway, the most proportion of heavy or large freight cars is distributed in Lane1 so that the ratio of small passenger cars is less than 5%. The ratio of small passenger cars goes up to over 40% in Lane2 yet and the ratio of heavy or large freight cars decreased to below

30%. In Lane3, the ratio of small passenger cars is 94.74% and the ratio of heavy or large freight cars is only 0.72%. On the contrast, when VTUS is used in the expressway, the large or middle passenger cars is of less proportion, but the ratio of small passenger cars is 35.83% and far more than its in lane1 with VTRS. In Lane2, the ratio of small passenger cars and heavy or large freight cars make large proportion. The ratio of small passenger cars is 77.41% and less than its in lane3 with VTRS.

4.2. Vehicle Type Characteristic with Different Operational Strategy

The distribution characteristic of vehicle type on the off-ramp diverging is always decided to the social-economic and industry feature in the region that is joined with off-ramp. The ratio small passenger car is of large proportion when area along with the expressway was developed. But if the secondary industry is the most important industry in the area along with the expressway, the ratio of heavy or large freight cars would be of the largest part of vehicles.

From the perspective of traffic flow, the distribution characteristic of vehicle type on the off-ramp diverging is depended on the operational strategy in each lane. The type of vehicle that it is allowed to travel in this lane is always of large proportion, and the number of the rest of vehicle type is seldom, when the VTRS is used. If the VTUS is used, the distribution characteristic of vehicle type is similar as the characteristic that when the VTRS is used. The difference of characteristic between the VTRS and VTUS is that the distribution of vehicle type on Lane3. The ratio of small passenger cars on the Lane3 is only about 80% in VTUS, however, it is exceed of 95% in VTRS. The most important is that many cars would travel illegally even if the lane is of vehicle type-restricted.

5. Headway Distribution

5.1. Distribution Fitting and Hypothesis Test

In the basis of vehicle type distribution above, there is large difference in vehicle type among lanes, so that the headway of each lane on the off-ramp diverging is also different, regardless of the VTRS or VTUS is used. Take the example of headway on deceleration lane, it is counted and described as histogram. It shows in table 2 and table 3 respectively.

In VTRS, the point of deceleration headway distribute on the intervals [1, 13]s, the maximum headway is 53.2s and the 85% headway is 20s approximately, the most of headway is small. While in VTUS, the point of deceleration headway distribute on the intervals [1, 12]s, the maximum headway is 37.1s and the 85% headway is 19s approximately

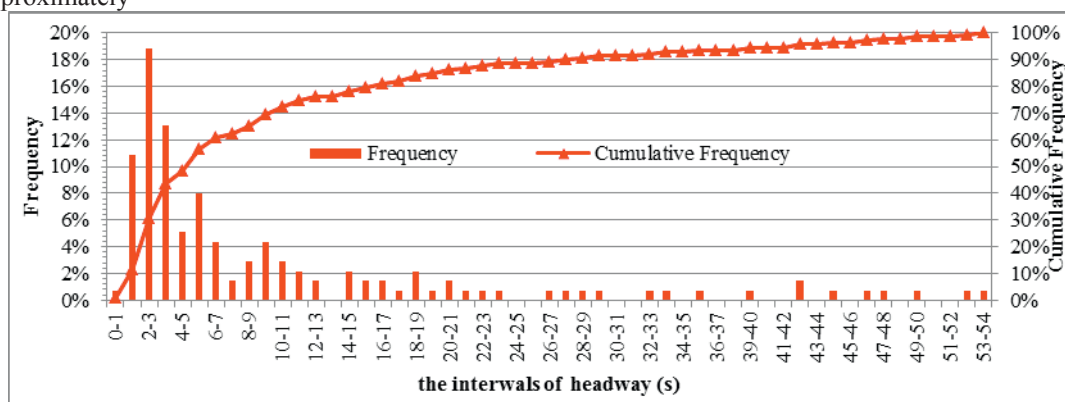


Fig 1 The headway characteristics of deceleration lane in use of VTRS

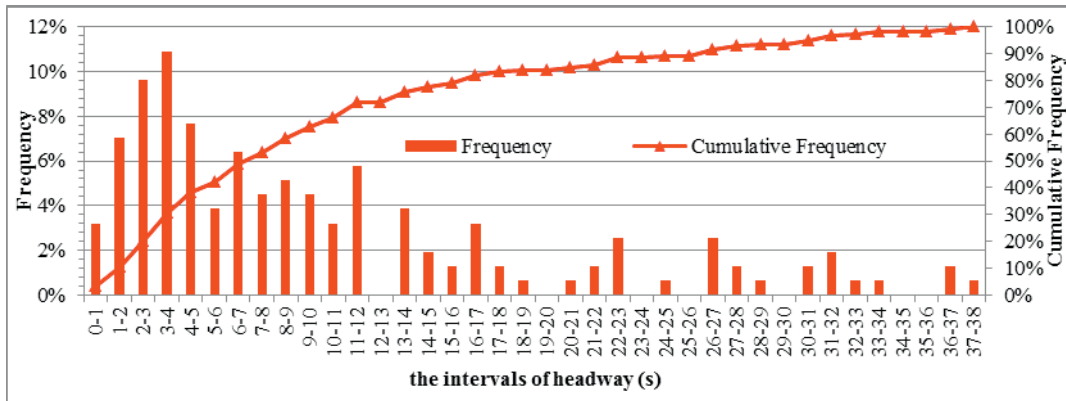


Fig 2 The headway characteristics of deceleration lane in use of VTUS

The Erlang distribution or the shift-negative-exponential distribution can well reflect the headway distribution according to reference 0(Wang Wei, Guo Xiucheng(2011): For the example of headway distribution in VTRS, the analysis step is as follows:

Step 1: Calculate the mean of sample \bar{t} , the variance of sample S^2 and the parameter l ;

$$\bar{t} = \frac{\sum_{i=1}^{54} f_i t_i}{\sum_{i=1}^{15} f_i} = \frac{1372}{138} = 9.94, S^2 = \frac{\sum_{i=1}^{54} f_i t_i^2}{N-1} - \frac{(\sum_{i=1}^{15} f_i t_i)^2}{N(N-1)} = 143.95$$

(1)

$$l = \frac{\bar{t}^2}{S^2} = \frac{9.94^2}{143.95} = 0.6866, \lambda = \frac{Q}{3600} = \frac{138 \times 2}{3600} = 0.077(\text{veh/t})$$

(2)

The parameter l should be an integer, so $l = 1$ in this calculate process.

Thus, the headway distribution function of deceleration lane on the expressway with VTRS as follows:

$$P(h \geq t) = \exp(-0.076t)$$

(3)

Step2: Hypothesis Test

According to the distribution function above, each interval theoretical frequency can be calculated, and χ^2 test can be used to do the hypothesis test.

The result:

$$\chi^2 = \sum_{i=1}^{54} \frac{f_i^2}{F_i} - N = 174.40 - 138 = 36.40 \quad (4)$$

There is only one unknown parameter in Erlang distribution, so the result is $r = 1$. let $\alpha = 0.05$, the result is:

$$\begin{aligned}\chi_{0.05}^2(K-r-1) &= \chi_{0.05}^2(16) = 26.296 \\ \chi^2 &> \chi_{0.05}^2(16) = 26.296\end{aligned}\quad (5)$$

Thus, the metioned above hypothesis should be refused, that is, headway distribution doesn't fit the first - order Erlang distribution.

Step3: Hypothesis Test Again

Generally speaking, the least headway always exists so that every vehicle can be braked in danger. We assumed that the headway distribution would fit the shift-negative-exponential distribution, and let $\Delta t = 0.5s, 1.0s, 1.5s, 2.0s$ respectively. Furthermore, the hypothesis would be test in use of χ^2 test. The result shows that the headway distribution fits the shift-negative-exponential distribution when $\Delta t = 2.0s$. The calculate result is showed in table 4.

Table 4 The parameters of headway distribution on the deceleration lane in use of VTRS

Mean \bar{t}	Variance S^2	λ	l	Δt	χ^2	α	$\chi_{0.05}^2$	Degree of Freedom
9.94	143.95	0.077	0.6866	2	25.24	0.05	26.296	16
Results of Hypothesis Test					$\chi_{0.05}^2 = 26.296 > 25.24$			
					It fits the shift-negative-exponential distribution			
Distribution Function					$P(h \geq t) = \exp[-0.076(t-2)]$			

Similarly, the headway distribution in each lane of expressway with different operational strategy can be calculated. The result shows in table 5.

Table 5 The characteristic of headway distribution on each lane in different operational strategy

Lane	Operational Strategy	Mean \bar{t} (s)	Variance S^2 (s)	Distribution Function
Deceleration Lane	VTRS	9.94	143.95	$P(h \geq t) = \exp[-0.076(t-2)]$
	VTUS	10.27	82.45	$P(h \geq t) = \exp[-0.087(t-2)]$
Lane1	VTRS	7.57	38.92	$P(h \geq t) = \exp(-0.13t)$
	VTUS	8.58	73.60	$P(h \geq t) = \exp(-0.07t)$
Lane2	VTRS	6.28	27.88	$P(h \geq t) = \exp(-0.16t)$
	VTUS	5.23	13.88	$P(h \geq t) = (1+0.21t)\exp(-0.21t)$
Lane	VTRS	4.56	17.13	$P(h \geq t) = \exp(-0.23t)$
	VTUS	3.82	10.59	$P(h \geq t) = \exp(-0.28t)$

5.2. Headway Distribution in Different Operational Strategy

There exists some regular pattern on diverging area headway of expressway off-ramp. In VTRS, the vehicle type is little, the headway distributes on the small intervals. While in VTUS, the velocity distribution of different is discrete, the intervals of headway distribution always become wide.

At the point of mean headway, the headway among adjacent lane is small if in VTRS, it is 1.3s and 1.7s respectively. In VTUS, the volume leads to different headway on each lane, and the headway among adjacent lane is large, it is 3.4s and 1.4s respectively.

With the seen of headway distribution on different lane, the shift-negative-exponential distribution can well reflect the headway distribution of deceleration lane, and the negative-exponential distribution can well reflect the headway distribution of Lane1 and Lane3, regardless of it is VTRS or VTUS. There exists difference on the Lane2 between the VTRS and VTUS is used. It fits the negative-exponential distribution and the second-order Erlang distribution, because the different type of vehicle redistribute as its operational rules on off-ramp diverging area.

6. Conclusion and Prospect

In this paper, it is analyzed that the distribution of vehicle type and headway on the off-ramp diverging area if the VTRS and VTUS is applied. Furthermore, the χ^2 test technology was used to do the hypothesis test on the headway distribution. The result shows that:

- First point: There exists main difference that the composition of vehicle type is simple on Lane3 when VTRS is used but it is complexity when VTUS is used.
- Second point: The shift-negative-exponential distribution can well reflect the headway distribution of deceleration lane, and the negative-exponential distribution can well reflect the headway distribution of Lane1 and Lane3, regardless of it is VTRS or VTUS. In Lane2, the headway distribution fits the negative-exponential distribution in VTRS and it fits the second-order Erlang distribution in VTUS.

On the basis of analysis that aim at traffic flow characteristic, it needs to be further studied that some parameters in the off-ramp diverging area, such as the curve of off-ramp, the length of deceleration lane, the site of sign and so on. Besides, it should be discussed that the safety and efficiency due to the difference of traffic characteristic among lanes with different strategy.

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References

- [1] G.F. Newell (1999). Delays Caused by a Queue at a Freeway Exit Ramp[J]. *Transportation Research Part B* 33: 337-350.
- [2] Cassidy, M.J., Anani, S.B., Haigwood, J.M. (2000). Study of Freeway Traffic Near an Off-Ramp[J]. California PATH Working Paper, UCB-ITS-PWP-2000-10.
- [3] Juan Carlos Muñoz, Carlos F. Daganzo (2002). The bottleneck of mechanism of a freeway diverge[J]. *Transportation Research Part A: Policy and Practice*, 36(6):483-505.
- [4] R. Horowitz and P. Varaiya (2000). Control design of an automated highway system[C].//*Proc. IEEE*, vol. 88, no. 7, pp. 913-925, Jul. P. Li, L. Alvarez, and R. Horowitz, "AHS safe control laws for platoon leaders," *IEEE Trans. Control Syst. Technol.*,

- [5]Chen Yongmao(2010). Study on Traffic Organization and Control of Expressway Expanding Reconstruction Section[D]: [Academic Degree of Master of Engineering].Nanjing: Southeast University
- [6]Li Tiezhu, Li Wenquan, Zhou Ronggui, et al(2001). Traffic Characteristics Analysis for Merging and Diverging in Acceleration and Deceleration Lane of Expressway[J]. Journal of Highway Transportation Research and Development, 18(4): 89-91.
- [7]Zhao Xiaocui, Yang Feng, Deng Bao(2012). Headway Distribution Characteristics of Diverging Area on Expressway Interchanges[J]. Journal of Highway Transportation Research and Development,29(2): 136-139.
- [8]Wang Wei, Guo Xiucheng(2011). Traffic Engineering(the 2nd Edition) [M]. Nanjing: Southeast University Press.